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Phonology Acquired through the Eyes and Spelling in Deaf Children

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Hearing and deaf children, ranging in age from 6 years 8 months to 14 years 4 months, and matched for general spelling level, were required to spell high-frequency and low-frequency words. Of interest was performance in relation to degree of exposure to Cued Speech (CS), which is a system delivering phonetically augmented speechreading through the visual modality. Groups were (a) hearing children, (b) deaf children exposed early and intensively to CS at home (CS-Home), and (c) deaf children exposed to CS later and at school only (CS-School). Most of the spelling productions of hearing children as well as of CS-Home children were phonologically accurate for high-frequency as well as for low-frequency words. CS-School children, who had less specified phonological representations, made a lower proportion of phonologically accurate spellings. These findings indicate that the accuracy of phonological representations, independent of the modality (acoustic versus visual) through which spoken language is perceived, determines the acquisition of phonology-to-orthography mappings. Analyses of the spelling productions indicate that the acquisition of orthographic representations of high precision depends on fully specified phonological representations.

Key Words: deafness; spelling; speechreading; Cued-Speech; phonology; morphology.

There is a large consensus that acquisition of an alphabetic orthography is not a purely visual process, but rather is guided by several sources of linguistic knowledge: phoneme-to-grapheme correspondences, orthographic letter redundancy, and morphology (Gibson, Shurcliff, & Yonas, 1970; Nunes, Bryant, & Bindman, 1997; Treiman, 1993; Treiman & Cassar, 1996). According to models

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of spelling acquisition (Ehri, 1992, 1998; Frith, 1985; Perfetti, 1992, 1997), phoneme-to-grapheme knowledge plays two important functions in the development of efficient spelling. First, phoneme-to-grapheme knowledge provides a back-up mechanism for spelling words never before encountered in print. Second, phoneme-to-grapheme knowledge functions as a mnemonic tool, enabling learners to retain letter-specific information about individual words in memory.

Given the relation between phonological knowledge and spelling acquisition, what might be the consequence to the speller of severe impairment in speech perception and production, as encountered by profoundly deaf children? Deaf children must write a language whose primary form, speech, they cannot hear or easily produce. Theoretical models of spelling that emphasize the role of phonological processes predict that deaf children should have difficulty with spelling. Indeed, this is generally the case. At the beginning of the 20th century, Gates and Chase (1926) found that deaf youngsters aged 13.6 years to 18.1 years were delayed by 2 to 5 years in spelling and by 6 to 8 years in reading. Subsequent investigators similarly found delay in word spelling and in word reading (Burden & Campbell, 1994; Campbell, 1994; Hanson, Shankweiler & Fischer, 1983; Hoemann, Andrews, Florian, Hoemann, & Jensema, 1976).

Can it be concluded that deaf children reach these levels of spelling achievement without any phonological support, as some authors have argued (Aaron, Keetay, Boyd, Palmatier, & Wacks, 1998; Gates & Chase, 1926; Templin, 1948)? Surprising as it may seem, studies performed over the last 20 years suggest rather that some deaf persons do have access to phonology for word spelling (Burden & Campbell, 1994; Dodd, 1980; Hanson, Shankweiler, & Fischer, 1983; Leybaert & Alegria, 1995). Of course, deaf children acquire knowledge about spoken language phonology through a very different language experience than that of hearing children. Hearing children's acquisition of phonology is determined by experience with audiovisual speech (Campbell, Dodd, & Burnham, 1998; McGurk & MacDonald, 1976). Deaf children's acquisition of spoken-language phonological units is largely influenced by visual experiences such as speechreading, fingerspelling, and reading, and by gestural experiences such as speaking.

In the case of individuals with profound hearing loss, speechreading frequently refers to the combination of visual and acoustic speech information, which could be processed at some minimal level. Speechreading constitutes the main mode of spoken-language perception by profoundly deaf children, and the main input for the acquisition of the phonological system (Dodd, 1976, 1987). Speechreading skills have also been identified as the best predictors of early reading and spelling development (Dodd, McIntosh, & Woodhouse, 1996; Hickson, Woodyatt, Cue, & Dodd, in press). However, even the most skilled speechreaders typically miss more than one third of the spoken words. The ambiguity of speechreading is due to the similarity in appearance of speech elements sharing the same place of articulation, like /p/, /b/, and /m/ (Erber, 1979; Walden, Prosek, Montgomery, Scherr, & Jones, 1977). Consequently, the phonological representations developed by deaf children from the speechread input are incomplete, inaccurate, and underspecified.

The extraction of regularities between orthographic units and phonological units is possible only when relatively systematic relationships between the phonological forms and the written forms of the words exist. Underspecified phonological representations can be insufficient to permit deaf children to extract such regularities. Two observations support this view. First, deaf children achieve lower spelling performance than hearing children for regular words (Leybaert & Alegria, 1995). Second, fewer of the misspellings produced by deaf children and adults can be considered as phonologically equivalent to the target word (Aaron et al., 1998; Burden & Campbell, 1994; Dodd, 1980; Hanson et al., 1983; Hoeman et al., 1976; Leybaert & Alegria, 1995). These two observations indicate that deaf children benefit less from the regularities between phonology and orthography. It is interesting to note, however, that some of the deaf youngsters' misspellings are compatible with the word's speechread image (e.g., in English SPONCH for *sponge*[1]; in French OUFERT for *ouvert*). This suggests that nonphonetic misspellings arise not because deaf children are unable to appreciate the mapping between written and spoken language, but rather from their difficulty in establishing an accurate phonological representation of specific words.

Let us assume that deaf children's spelling is limited by speechreading, not as a visual coding but as a partial coding. Therefore, the addition of complementary visual information that resolves the ambiguity of the speechread signal could improve the accuracy of their phonological representations and, consequently, their ability to use the relationship between phonology and orthography. The present study is aimed at evaluating this hypothesis by examining the effect of exposure to Cued Speech (CS) on deaf children's spelling. CS is a system which visually delivers phonetically augmented speechreading. In Part I, I examine the hypothesis that the accuracy of children's phonological representations determines the use of phonology-to-orthography mappings for spelling, independently of the modality (acoustic versus visual) through which language is perceived. In Part II, I examine the hypothesis that the development of precise orthographic representations depends on fully specified phonological representations.

PART I: EFFECT OF CUED SPEECH ON THE ACQUISITION OF PHONOLOGY-TO-ORTHOGRAPHY MAPPINGS

CS was invented in 1968 to aid deaf children in the task of resolving the ambiguity inherent in speechreading (Cornett, 1967; see Duchnowski et al., 1998, for the presentation of a computerized cueing system). In CS, the speaker complements speech with manual cues. A cue consists of two parameters, as shown in Fig. 1. Hand shapes (eight in French) disambiguate the consonants and hand locations (five in French) disambiguate the vowels.

[1] Throughout this paper, the convention will be used that target words are in italics and the subject's written response in capitals.

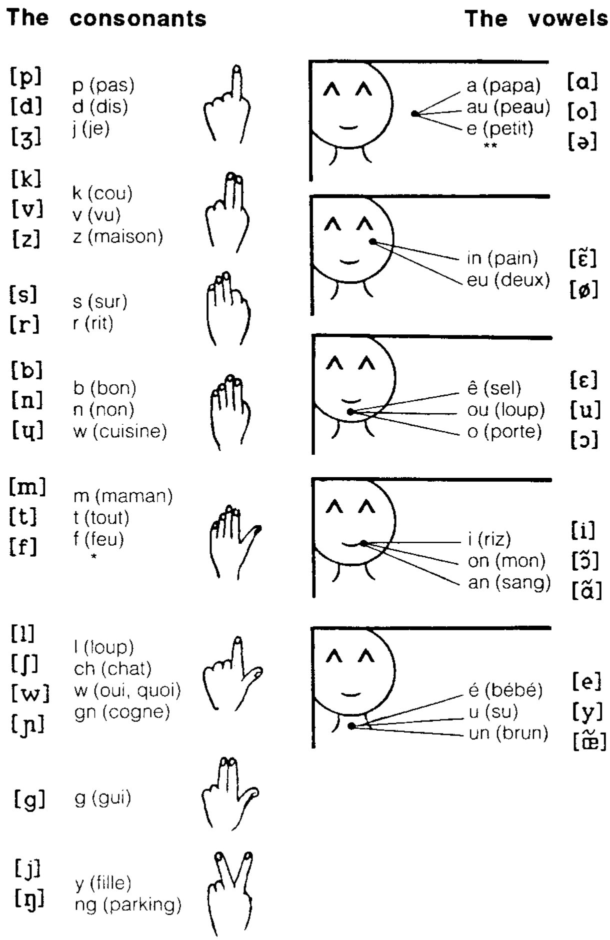

FIG. 1. The manual Cued Speech cues for the French language. A single asterisk indicates that this hand shape is also used to code any vowel not preceded by a consonant (e.g., *arrête*). Two asterisks indicate that this hand location is also used to code any isolated consonant (e.g., *sec, prof*) and any consonant followed by a schwa (e.g., *lune*).

Each time the speaker pronounces a consonant–vowel (CV) syllable, he or she produces a cue. The integration of spoken and manual information points to a single, unambiguous, phonological percept that children could not have achieved from either source alone (see Leybaert, Alegria, Hage, & Charlier, 1998, for a more detailed description). The effectiveness of CS in improving the speech reception of its users is well documented (Alegria, Charlier, & Mattys, 1999; Nicholls & Ling, 1982; Périer, Charlier, Hage, & Alegria, 1988), with greater effects from earlier and more exposure (i.e., exposure before age 3 years at home). Early and intensive exposure to CS is also associated with greater accuracy in rhyme-judgment and rhyme-generation tasks (Charlier & Leybaert, in press). In addition, children who grow up communicating with CS develop reading skills comparable to those of their normal-hearing peers (Wandel, 1990).

The first aim of the present study was to examine whether deaf children who use CS early make use of phonology-to-orthography mappings for word spelling to the same extent as do hearing children. Three groups of children were tested: children educated early with CS at home (CS-Home group), children educated with CS late at school (CS-School group), and hearing children. The children were asked to spell high- and low-frequency words. If children from the CS-Home group possess accurate phonological representations, they can extract regularities between letters (or letter groups) and specific combinations of manual cues and lip movements. They should produce a similar rate of phonologically acceptable responses as hearing children, for high-frequency as well as for low-frequency words. Their performance will contrast with that of CS-School children, who have underspecified phonological representations (Charlier & Leybaert, in press).

Method

Participants. The matching of deaf children with hearing children is always a tricky problem. A chronological-age matching design did not seem suitable, because the differences between absolute level of spelling performances might be so large that they would preclude any sensible comparison. A reading-matched design is also problematic, because deaf children are more impaired in reading than in spelling (Gates & Chase, 1926; Hanson et al., 1983). Therefore, it was decided to match the groups on general spelling level.

Three groups of children were recruited, matched on a spelling score that comes from the data collected in the actual experiment reported (see “Percentage of correct spelling” in Table 1). All deaf children met the following criteria: (a) bilateral profound sensorineural hearing loss >90 dB in the better ear across three frequencies of the speech range (0.5, 1, and 2 kHz), (b) no other significant handicapping condition, (c) hearing loss onset prior to 18 months of age. The deaf children were all equipped with two acoustical hearing aids worn during the experiment. Speech intelligibility and speechreading abilities were evaluated by children’s teachers on 6-point scales (1 being “very poor,” 6 being “perfect”).

The CS-Home group included 28 children who received the French version of CS at home, meaning that at least one of their parents used it in daily communication, from a mean age of 18 months. All of them had hearing parents. They were mainstreamed in ordinary schools for hearing children, where they were provided with CS by interpreters. The CS-School group consisted of 28 children who were exposed to CS in their school and inconsistently in their home environment, from a mean age of 3 years 2 months. Six of them had deaf parents. The other children had hearing parents. Twelve of them were mainstreamed in ordinary schools and the others were enrolled in special schools for the deaf. A hearing control group consisted of 30 children. Further characteristics of the participants are shown in Table 1.

TABLE 1
Characteristics of Hearing, CS-Home, and CS-School Participants

	Hearing	CS-Home	CS-School
N	30	28	28
Male	15	13	18
Female	15	15	10
	Chronological age[a]		
M	8;9	8;10	11;1
Range	6;8–10;8	6;8–12;2	8;0–14;4
Status of the parents	—	28 H[b]	6 D/22 H
	Percentage correct spelling		
M	77.0	79.2	73.3
SD	19.3	19.4	15.9
	Reading score[c]		
M	21.7	21.5	14.5
SD	8.2	9.6	8.1
	Hearing loss[d]		
M	—	98	98
SD		6.3	7.8
	Speech intelligibility		
M		3.8	3.8
Range		1–5	1–5
	Speechreading ability		
M		4.0	4.2
Range		1–5	1–5

[a] Chronological age is given in years;months.
[b] D = deaf parents; H = hearing parents.
[c] Maximum score = 36.
[d] In decibels, at the better ear.

All the participants also passed a silent-reading sentence-completion test (Lobrot, 1973). The test consists of 36 sentences. For each sentence, subjects have to choose the appropriate final word from five options. The score is the number of sentences correctly completed in a fixed time of 5 min. The score provides a measure of overall reading efficiency, including word recognition ability as well as lexical and syntactical abilities. The three groups of children differed significantly in reading achievement, $F(2, 72) = 6.00$, $p < .005$. Post hoc testing (Tukey HSD) revealed that the performance of the CS-School group was significantly lower than the performances of both the hearing and the CS-Home groups ($p < .05$).

Material. The stimuli used in the spelling task consisted of one list of 42 high-frequency French words and one list of 45 low-frequency words (see Appendix for the list of stimuli). The words, selected after consultation with the deaf children's teachers, contained at least one of the graphonemes tested in Part II and formed part of the oral or signed vocabulary known by deaf children in primary school. According to the frequency count provided in BRULEX, a database containing approximately 30,000 French words (Content, Radeau, & Mousty, 1990), the mean log frequencies of the high- and low-frequency words were 3.87 and 3.21, respectively.

Procedure. Participants had to write the words down on experimental test pages on which the target words were suggested by a drawing and/or by a sentence context. If they did not succeed in discovering a target word, an alternative definition was provided. The sign (from sign language) corresponding to the target word was produced for deaf subjects. The words were not pronounced to the hearing or to the deaf participants. Hearing and deaf children were tested in their own classroom. The children had as much time as they needed to complete the spelling test.

Results and Discussion

Percentage of correct responses. Each word was scored as correct if its spelling was entirely correct. The absence of response to a target was considered as an omission. For each list, the percentage of correct spelling responses was computed by dividing the number of words correctly spelled by the number of words in the list minus the number of omissions. The mean percentage of correct word spelling is presented in Table 2.

The data were entered into a 3 (Hearing Status) × 2 (Word Frequency) ANOVA with Hearing Status as the between-subjects factor and with repeated measures on Frequency. The percentage of correct spellings was taken as the dependent variable. The main effect of Hearing Status was by definition not significant, $F(2, 83) < 1$. The analysis revealed a main effect of Frequency, $F(1, 83) = 104.67$, $p < .0001$, and a significant two-way interaction between Hearing Status and Frequency, $F(2, 83) = 10.37$, $p < .0001$. An examination of Table 2 showed that the effect of Frequency was quantitatively larger in the CS-School group (19.2%), intermediate in the hearing group (11.8%), and smaller in the CS-Home group (5.8%).

Error types. An examination of the misspellings allows us to ask whether a similar level of competence in spelling builds on the same underlying cognitive ability for hearing, CS-Home children, and CS-School children. Misspellings were classified into five categories: (1) *phonological substitutions,* misspellings with pronunciations that are identical to those of the targets (e.g., SITRON for *citron*, CHANBRE for *chambre*); (2) *context-sensitive errors*, misspellings that could be pronounced as the target words if one did not consider the orthographic context (e.g., spelling GERIR /ʒerir/ instead of *guérir* /*g*erir/); (3) *nonphonological substitutions,* misspellings preserving the number of syllables and number of phonemes of the target but not the identity of the phonemes (e.g., RAISON

TABLE 2
Mean Percentages of Correct Spellings and Percentages of Errors of Different Types as a Function of Word Frequency and Group of Participants

	High-frequency words			Low-frequency words		
	Hearing	CS-Home	CS-School	Hearing	CS-Home	CS-School
Correct responses						
M	82.9	82.2	82.9	71.1	76.4	63.7
SD	17.7	19.9	11.8	22.4	19.6	21.5
Errors						
Phonological substitutions						
M	14.5	11.8	6.7	23.9	15.8	11.9
SD	17.0	12.7	6.1	18.8	13.0	8.0
Context-sensitive						
M	1.8	1.8	2.3	2.8	1.6	2.7
SD	2.9	3.1	2.1	3.4	2.4	3.8
Nonphonological substitutions						
M	0.2	2.0	3.9	1.0	2.6	10.9
SD	0.7	3.4	4.7	1.7	4.1	9.0
Transpositions						
M	0.0	0.1	0.4	0.0	0.1	0.5
SD		0.4	1.1		0.4	1.2
Others						
M	0.5	2.2	3.8	1.2	3.4	10.3
SD	1.3	3.6	5.6	2.1	4.4	11.6
Phonologically accurate responses						
M	99.2	95.8	91.9	97.8	93.9	78.3
SD	1.6	6.4	9.3	3.0	7.5	7.8

/rɛzɔ̃)/ for *raisin* /rɛzɛ̃/; TIGARETTE /ti*g*arɛt/ for *cigarette* /si*g*arɛt/). They could be a consequence of inaccurate phonological representations, in which the identity of each phoneme is not clearly defined (Hanson et al., 1983); (4) *transpositions*, misspellings containing the correct letters of the target but in a wrong order (e.g., TARIN for *train*). Such errors indicate a misuse of phonological knowledge in the encoding of the word's orthographic form; (5) *others*, misspellings including omission or insertion of one or more phoneme (e.g., REVLVER for *revolver*), as well as multiple errors (e.g., GIERF for *cerf*).

This analysis of the errors involved the whole word produced. The percentage of errors in each category (see Table 2) was calculated by dividing the number of errors for that category by the number of words in the list minus the number of omissions. Given the small number of errors involved, the discussion of error types is confined to descriptive analysis of the differences in the raw data.

An examination of Table 2 revealed striking differences between the errors made by the three groups. Hearing children produced mainly phonological substitutions, confirming that they rely on mappings between phonology and orthography. Of major concern to the present study was the finding that CS-Home children also made a majority of phonological substitutions, for high-frequency as well as for low-frequency words. Their results contrasted with those of the CS-School children, who produced more errors that were not phonological substitutions, particularly for low-frequency words, indicating a lower ability to use phonology-to-orthography mappings. Consistent with previous findings (Hanson et al., 1983; Leybaert & Alegria, 1995) was the observation that deaf children made transpositions errors that did not preserve the phonetic representation of the target word. These errors were slightly more frequent in the CS-School group. Finally, both groups of deaf children made more "other" errors than the hearing children. Some of these errors (e.g., FEUR for *fleur;* MOUTACHE for *moustache*) could be interpreted as resulting from access to inaccurate phonological representations. Other errors, however, display little evidence, if any, of representations detailed at the segmental level (e.g., ESCORLR for *escalier*). The percentage of "other" errors was slightly higher in CS-Home children than in hearing children, and much higher in the CS-School group.

Phonologically accurate responses. A score of phonologically accurate responses was computed by adding all cases in which each phoneme in the word was represented by a grapheme with the corresponding pronunciation: correct responses, phonological substitutions, and context-sensitive errors. This score provides a global estimation of ability to use phonology-to-orthography mappings.

The mean percentages of phonologically accurate responses are presented in Table 2. The data were entered in a 3 (Hearing Status) $\times$ 2 (Frequency) ANOVA with Hearing Status as the between-subjects factor and with repeated measures on Frequency. The analysis revealed significant effects of Hearing Status, $F(2, 83) = 17.45$, $p < .0001$, and of Frequency, $F(1, 83) = 39.87$, $p < .0001$, and a significant two-way interaction between Frequency and Hearing Status, $F(2, 83) = 19.72$, $p < .0001$. A simple main effect analysis was used to explore the interaction. This revealed a significant effect of Hearing Status for high-frequency words, $F(2, 83) = 9.13$, $p < .001$, as well as for low-frequency words, $F(2, 83) = 20.35$, $p < .0001$. Tukey HSD post hoc tests ($p < .05$) showed that for high-frequency words the CS-School group significantly differed from the hearing group; for low-frequency words, CS-School children differed from both hearing and CS-Home children.

Two additional ANOVAs were performed on the percentage of phonologically accurate responses in order to control for differences between the groups in schooling experience and in the hearing status of the parents. The first one included only children from hearing parents, reducing the CS-School group to 22 subjects. Their mean percentages of phonologically accurate responses for high-and low-frequency words were 92.8% and 83.0%, respectively. The pattern of significant effects and interactions was the same as in the general analysis. The second one considered only children who were mainstreamed in ordinary schools, reducing the CS-School group to 12 participants. Their mean percentages of phonologically accurate responses for high- and low-frequency words were 96.5% and 87.1%, respectively. The only difference compared to the general analysis was that the CS-School group did not differ from the hearing for high-frequency words.

PART II: EFFECT OF QUALITY OF PHONOLOGICAL REPRESENTATIONS ON THE ACQUISITION OF ORTHOGRAPHIC REPRESENTATIONS

The aim of spelling acquisition is to acquire a large number of orthographic representations which make it possible to generate orthographic productions rapidly and without errors. Theorists of reading acquisition hypothesize that orthographic representations vary in their precision and evolve toward completeness and specification (Perfetti, 1992, 1997). For example, in children's attempt to write the French word *train* /trɛ̃/, two levels may be distinguished. At Level 1, children spell each phoneme with the dominant transcription, thus producing TRIN. At that level, one can assume that the graphemes T and R are stable components of the orthographic representation, while IN is variable and in a state of change. At Level 2, children produce the whole word correctly, meaning that all constituent graphemes are now stable components of the orthographic representation.

Accurate phonological representations may facilitate the development of orthographic representations of high precision. First, the presence of phonological segments forces children to pay attention to the letters that represent them. In addition, the possible spellings for a word are limited to those compatible with the phonological form (e.g., TRIN, TREIN, TRAIN). This renders selection of the appropriate spelling easier than when no such constraints exist. For children with inaccurate phonological representations, the development of orthographic representations may take a longer time. Graphemes corresponding to underspecified phonemes may be unstable in the orthographic representation. In addition, the possible spellings for a word are less constrained, which renders selection of the appropriate spelling more difficult.

The general aim of Part II is to test the hypothesis that the acquisition of orthographic representation of high precision depends upon accurate phonological representations. Therefore, four aspects of the French spelling system were examined in the hearing, CS-Home, and CS-School groups: phoneme-to-grapheme dominance, spelling of consonant clusters, spelling of context-dependent rules, and morphological spelling. For this purpose, the data collected in Part I were subjected to in-depth analyses.

Phoneme-to-Grapheme Dominance

Although French orthography is quite consistent for reading, this is not the case for spelling; most of the phonemes can be spelled in different ways (Peereman & Content, 1999; Véronis, 1986). The phoneme-to-grapheme correspondences (hereafter, graphonemes, after Véronis, 1986) have different frequencies in French orthography. For example, the phoneme /ɛ̃/ at the end of words is most frequently transcribed by the grapheme IN. This graphoneme will be labeled as *dominant* and represented by /ɛ̃/#->IN. The same phoneme has *nondominant* transcriptions: AIN, EIN.

Through exposure to print and, in some cases, perhaps as a result of some direct phonic instruction, children will establish a strong connection between the phoneme /ɛ̃/ and the dominant grapheme. In the absence of any orthographic representation, children will spell every word containing /ɛ̃/ on the basis of the strongest connection. This would entail correct responses for words ending with the dominant graphoneme (e.g., *sapin*) but errors for words ending with the nondominant graphoneme (e.g., producing BIN for *bain*). With more experience with print, appropriate connections will be selected for each particular word, while inappropriate connections will be inhibited or suppressed. In the case of nondominant graphonemes this process necessitates more exposure to print, because a stronger connection has to be suppressed. The process of selecting appropriate connections occurs first for high-frequency words and then for low-frequency words (Alegria & Mousty, 1994). Children may thus be able to spell high-frequency words containing nondominant graphonemes accurately, while still generating incorrect spellings for low-frequency words.

Children who have inaccurate phonological representations will benefit less from the generativity of phonology-to-orthography mappings. If phonemes are poorly specified, they could be connected with a larger number of graphemes. For example, the phoneme /ɛ̃/ has a lip shape in French similar to that of the phoneme /ɛ/, and could be spelled not only IN, AIN, or EIN, but also AI, E, or EI. This would make the extraction of a dominant rule more difficult. Consequently, these children will not spell low-frequency words containing the phoneme /ɛ̃/ systematically with IN.

These ideas lead to the following predictions: (1) better performance in spelling dominant graphonemes than in spelling nondominant graphonemes in the hearing and in the CS-Home group, and a reduced effect of dominance in CS-School children; (2) an interaction between the effect of graphoneme dominance and word frequency in hearing and CS-Home children; accuracy of spelling of nondominant graphonemes, but not of dominant graphoneme, will be lower for low-frequency words than for high-frequency words. This interaction would be less apparent in CS-School children; (3) a predominance of use of dominant graphoneme in the errors made on nondominant graphonemes in hearing and CS-Home children. This pattern would be attenuated in CS-School children.

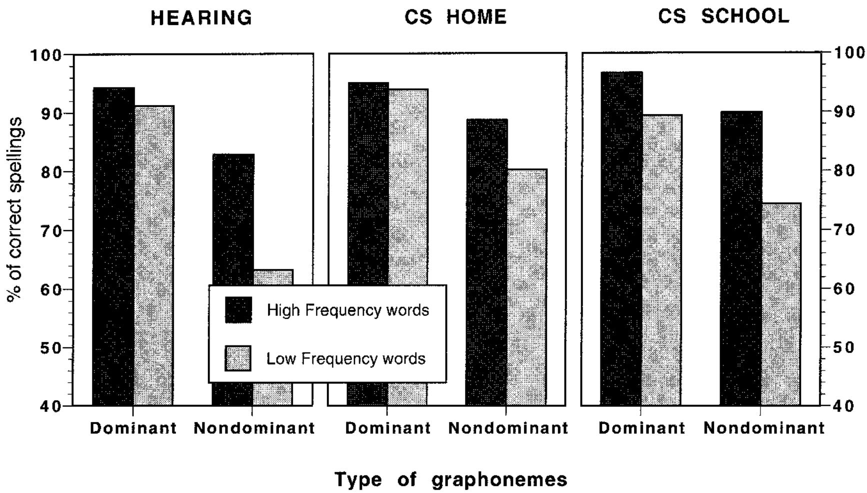

FIG. 2. Mean percentages of correct spellings for dominant and nondominant graphonemes as a function of word frequency for hearing, CS-Home, and CS-School children.

Method

Material. Three phonemes (/s/, /k/, and /ɛ̃/) were selected because they had a dominant and a nondominant transcription, estimated using the BRULEX database (Content et al., 1990). The dominant graphonemes were /s/ at the beginning of words and before the letters E and I spelled with the grapheme S (#/s/E,I→S), /k/ at the beginning of words and before the letters A and O spelled C (#/k/A,O→C), and /ɛ̃/ at the end of words spelled IN (/ɛ̃/#→IN). The non-dominant transcriptions for these three phonemes in the same orthographic context were #/s/E,I→C, #/k/A,O→QU, and /ɛ̃/#→AIN. In each list, the dominant and nondominant transcriptions consisted of nine items (see Appendix). For each list, the scores for the dominant and nondominant graphonemes were thus averaged over nine items.

Results and Discussion

A correct response was credited if the child had correctly spelled the graphoneme under investigation. For example, for the word *ciel*, productions like CIEL, CIELLE, and CEIL were considered as correct, while productions like SIEL, SIELLE, and SEIL were scored as incorrect. The cases when the child did not answer or spelled another word were considered as omissions. In each condition, the percentage of correct responses was computed by dividing the number of correct responses by the number of items minus the number of omissions. The mean percentages of correct responses are presented in Fig. 2 for the three groups of subjects.

The data were entered in a 3 (Hearing Status) × 2 (Dominance) × 2 (Frequency) ANOVA, with Hearing Status as between-subjects factor and with repeated measures on Frequency and Dominance. This analysis revealed no significant effect of Hearing Status, $F(2, 83) = 2.07$, *ns*. There was a significant effect of Dominance, $F(1, 83) = 38.32$, $p < .001$: dominant graphonemes were better spelled than nondominant graphonemes. There was also a significant effect of Frequency, $F(1, 83) = 62.20$, $p < .001$: graphonemes in high-frequency words were spelled more accurately than those in low-frequency words. A significant two-way Dominance by Frequency interaction, $F(1, 83) = 19.53$, $p < .001$, appeared. An examination of Fig. 2 revealed that the effect of Dominance was stronger for low-frequency words than for high-frequency words. The analysis also revealed a significant Frequency by Hearing Status interaction, $F(2, 83) = 3.50$, $p < .05$. Inspection of Fig. 2 showed that the effect of Frequency was larger in the hearing (11.4%) and the CS-School groups (10.9%) than in the CS-Home group (4.8%). Contrary to the hypothesis, neither the two-way interaction between Dominance and Hearing Status nor the three-way Dominance by Frequency by Hearing Status interaction was significant. Although the statistical analyses did not reveal any significant differences between the groups, it is worth noting that the effect of frequency on dominant graphonemes is larger for CS-School children (7.3%) than for the hearing (3.1%) or for CS-Home children (1.1%).

An analysis of spelling errors revealed that the most frequent error in spelling dominant graphonemes included in high-frequency words consisted of using the nondominant graphoneme (e.g., CEL for *sel*) in the three groups (hearing, 5.3% of the trials; CS-Home, 3.9%; CS-School, 2.1%). For low-frequency words, errors consisting of using the nondominant grapheme reached 8.4% of the trials in the hearing, 5.8% in the CS-Home children, but only 3.3% in the CS-School children. CS-School children however, made a larger number of other errors (e.g., TIGARETTE for *sigarette*) that were not phonologically accurate renderings of the phoneme target (7.4% of the trials in spelling low-frequency words). When the nondominant graphoneme was appropriate, the major source of errors in high-frequency words consisted of using the dominant graphoneme for hearing (15.1% of the trials), CS-Home (6.5%), and CS-School children (3.3%). The tendency to use the dominant graphoneme increased in the three groups when they were spelling low-frequency words (hearing, 35.1% of the trials; CS-Home, 15.8%; CS-School, 13.5%). The CS-School children differed from the other groups in making more other errors which were not phonologically accurate renderings of the phonemes under consideration, for high-frequency words (4.6% of the trials) and especially for low-frequency words (9.2%).

To summarize, these findings indicate that all children used the relationship between phonology and spelling. The CS-School children, however, used more graphemes that could not be pronounced like the target phoneme. Consequently, they do benefit from the possibility of spelling dominant graphonemes present in low-frequency words to the same extent as the hearing and CS-Home children.

Consonant Clusters

The precision of the orthographic representation could be variable even for phonemes that have entirely predictible spellings. In the case of consonant clusters, phonological principles allow one to make predictions concerning the representation of consonants. Liquids that follow initial stops or fricatives in a CCV onset, and in intersyllabic clusters, are more likely to be prone to omission when spelled (Perfetti, 1992). Evidence supporting this idea has been found for both English and French hearing spellers. Bruck and Treiman (1990) showed that beginning spellers experience difficulty with consonant clusters at the beginning of English words. Their predominant spelling error is to omit the second (or third) consonant of the cluster, as in BO for *blow* or SET for *street*. French-speaking children spelled words and pseudowords less accurately when they contained consonant clusters than when they did not. This effect was larger in Grade 2 than in Grades 4 and 6, indicating that consonant clusters create more difficulty in spelling at the beginning of literacy (Leybaert & Content, 1995). Sprenger-Charolles and Siegel (1997) relied on the hierarchy of sonority theory to explain the deletion of consonants by French-speaking children. The most sonorant consonants are deleted, whether they are in second position after a less sonorant consonant in an onset cluster (e.g., TIBUL for *tribul*) or in first position before a less sonorant consonant in an intersyllabic cluster (e.g., TIBUL for *tirbul*).

Cluster reductions have also been observed in deaf children's written productions (Dodd, 1980; Leybaert & Alegria, 1995). One factor that could make the spelling of a consonant cluster difficult for them is the fact that the second consonant is nearly invisible in speechreading. The use of CS may play a positive role in the perception of consonant clusters. For example, a CCV syllable like /tr/ is produced in CS with two different hand configurations: the first one corresponds to the initial consonant /t/ and the second one corresponds to the CV phonemes /rɛ̃/. The same principle applies to the coda: the first syllable of the CVC/CVC word *moustache* /mustaʃ/ is produced with a first hand configuration corresponding to the initial CV phonemes (/mu/) and a second one corresponding to the coda /s/. The high visibility of the consonants in CS could lead deaf children to include all of them in the phonological representation, and, therefore, facilitate the development of a full orthographic representation.

In the present experiment, the spelling of /r/, /l/, and /s/ was compared in consonant clusters and in control structures at the beginning of a syllable. These graphonemes were included either in high-frequency or in low-frequency words. Different patterns are expected for the three groups. For hearing and CS-Home children, a slight detrimental effect of consonant clusters on the spelling of /r/, /l/, and /s/ could be observed, with little or no effect of frequency, while the performance of CS-School children could be more adversely affected for consonant clusters, especially for low-frequency words.

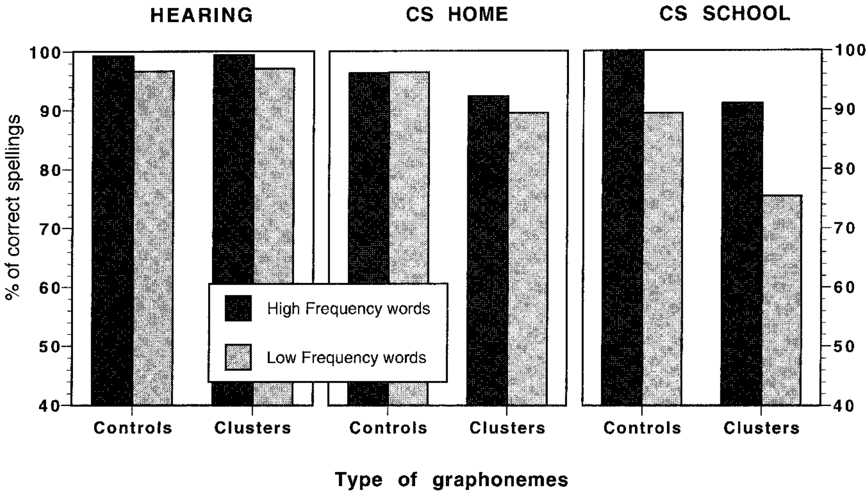

FIG. 3. Mean percentages of correct spellings for consonants in control structures (**C**V or V**C**V) and in clusters (C**C**V or (C)V**C**/C as a function of word frequency for hearing, CS-Home, and CS-School children.

Method

Material. In each list the /r/, /l/, or /s/ was tested six times in consonant clusters: three times in the context of a complex onset and three times in the context of the coda of the first syllable of a bisyllabic word, that is, before an onset. The control graphonemes /r/, /l/, and /s/ were also tested six times: three times in simple onsets at the beginning of the word and three times at the beginning of the second syllable (see Appendix). For each list, the score for consonant clusters was thus averaged over six items and the score for control graphonemes was averaged over six other items.

Results and Discussion

A correct response was credited if the child's production contained an R or an L at the expected place. For example, for the word *revolver,* productions like RELOVER, REVLVER, and RIGVER were scored as correct, while productions like EVOLVER and EVLVER were scored as incorrect. The mean percentages of correct responses are presented in Fig. 3 for the three groups of participants.

The data were entered in a 3 (Hearing Status) $\times$ 2 (Phonological structure, consonant clusters and controls) $\times$ 2 (Frequency) ANOVA, with Hearing Status as between-subjects factor and with repeated measures on Phonological Structure and Frequency. The analysis revealed a significant effect of Hearing Status, $F(2, 83) = 9.82$, $p < .001$, of Phonological Structure, $F(1, 83) = 31.13$, $p < .001$, and of Frequency, $F(1, 83) = 18.49$, $p < .001$. A significant interaction between Hearing Status and Frequency appeared, $F(2, 83) = 7.98$, $p < .005$.

TABLE 3
Mean Percentages of Correct Responses for /r/ and /l/ as a Function of Phonological Structure and Group of Subjects

	Hearing	CS-Home	CS-School
		CVCV (e.g., *r̲aisin*)	
M	98.6	96.3	96.2
SD	4.2	7.9	6.2
		CCV (e.g., *tr̲ain*)	
M	97.2	94.4	91.0
SD	7.7	10.9	12.5
		CVC/C (e.g., *car̲table*)	
M	99.1	87.6	75.0
SD	3.6	17.5	18.5

Subsequent analyses performed for each group separately revealed that the effect of Frequency was significant in the CS-School group $F(1, 27) = 9.43$, $p < .005$, but not in the other two groups. The analysis also revealed a significant interaction between Hearing Status and Phonological Structure, $F(2, 83) = 11.92$, $p < .001$. Subsequent analyses performed for each group separately revealed that the effect of Phonological Structure was significant in the CS-School group, $F(1, 27) = 32.20$, $p < .001$, and in the CS-Home group, $F(1, 27) = 7.38$, $p < .05$, but not in the Hearing group. While phonological structure does not affect the spelling of children with normal hearing, this factor had a clear influence on both groups of deaf children.

The effect of phonological structure in the CS-Home group was unexpected. One possibility is that it arises from an insufficiently detailed input. It is possible that the additional hand configuration required by the coda of CVC/C words is produced rapidly in order to keep the speech rate constant. In this case visual perception of the word in CS is similar to its perception in speechreading. In CCV words, however, the second consonant is probably coded in a very visible way because the hand configuration corresponding to it supports the production of the vowel. This reasoning leads us to predict that, compared to the performance for control graphonemes, the performance for /r/, /l/, or /s/ should be more adversely affected in CVC/C structures than in CCV structures. To test this, the mean percentages of correct responses for /r/, /l/, and /s/ present in the control graphonemes, CCV, and CVC/C were computed, and they are presented in Table 3.

These data were entered in a 3 (Hearing Status) × 3 (Phonological Structure: control, cluster, and coda) ANOVA. This analysis revealed a significant effect of Hearing Status, $F(2, 83) = 14.85$, $p < .001$, and of Phonological Structure, $F(2, 166) = 28.59$, $p < .001$. A Tukey HSD test showed that all the groups differed from one other ($p < .05$). The analysis also revealed a significant interaction between Phonological Structure and Hearing Status, $F(4, 166) = 12.60$, $p < .001$. Further analyses performed for each group separately showed that the effect of Phonological Structure was significant in the CS-School group, $F(2, 54) = 26.21$, $p < .001$, and in the CS-Home group, $F(2, 54) = 7.5$, $p < .05$, but not in the hearing group, $F(2, 58) = 1.08$. A posteriori comparisons made in each group of deaf children separately (Bonferronni–Dunn for dependent observations) showed that the performance for /r/, /l/, and /s/ in coda was significatively lower than for the control graphonemes both for CS-School and for CS-Home children. No significant difference was obtained between performances for /r/, /l/, and /s/ in cluster and in control graphonemes in either group.

These analyses thus indicate that the coda at the end of the first syllable of a bisyllabic word is difficult to embed in deaf children's orthographic representations. This is true even for children who have received CS early and intensively.

Context-Dependent Rules

Some of the phoneme-to-grapheme mappings are context-dependent in French orthography. For instance, the phonemes /ɔ̃/ and /ɑ̃/ are transcribed by the digraphs ON, AN, and EN except when followed by the letters P and B, in which case they are transcribed as OM, AM, and EM. This is a purely orthographic rule: ON, AN, and EN can never be found before P or B. The transcription of the phoneme /*g*/ is also context dependent: the letter G is used before the written vowels A, O, and U, and the letters GU before E and I. This is an orthographic *and* phonological rule, because the letter G also exists before E and I for transcribing the phoneme /ʒ/. Children must take into account both the orthographic context and the word pronunciation to spell correctly words containing the /g/→GU graphoneme.

Consider two hypothetical levels of skill in spelling context-dependent rules. At Level 1, children establish strong connections: /ɔ̃/→ON and /*g*/→G. At Level 2, their representation of graphemes becomes context sensitive. Their orthographic representation now includes knowledge that /ɔ̃/ before P and B is strongly mapped to OM and that /*g*/ before E and I is closely associated with GU. This occurs first for high-frequency words and then for low-frequency words (Alegria & Mousty, 1996). Underspecified phonological representations could affect the acquisition of context-sensitive rules, and more particularly of the /g/E,I→GU mapping. If representations of phonemes are underspecified, at Level 1 /ɔ̃/ will be connected not only with ON and OM but also with O and OU, for example; similarly, /g/ will be mapped to G and GU, but also to K or T, D. At Level 2, the connection between /ɔ̃/ and OM will become the strongest one, because ON is orthographically illegal before P or B. However, the phoneme /g/ could still be mapped strongly to both the G and the GU graphemes, because both graphemes are orthographically possible before E and I and children do not have the phonological clue which allows them to choose the appropriate spelling.

These ideas lead to the following predictions: (1) no difference between the /ɔ̃/B,P→OM rule and the /g/E,I→GU rule in hearing and CS-Home children,

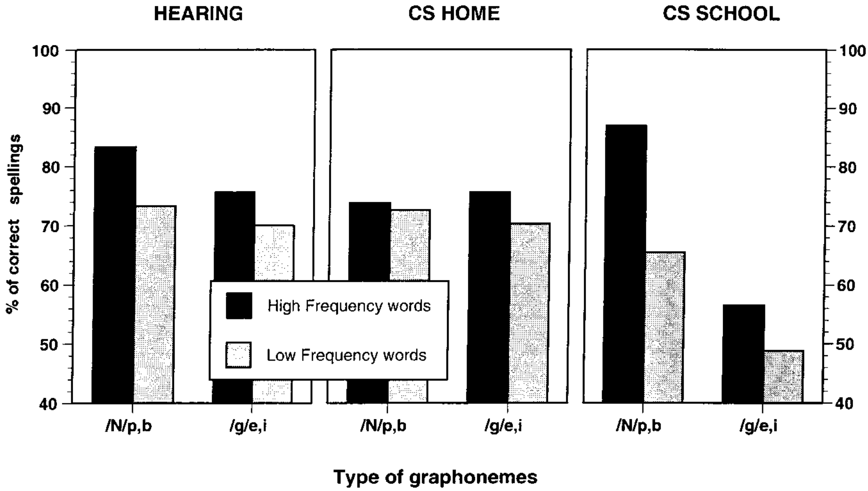

FIG. 4. Mean percentages of correct spellings for /ɔ̃/ B,P→OM, or /ã/ B, P→AM (indicated as /N/p,b) and /g/E, I→GU (indicated as /g/e,i) graphonemes as a function of word frequency for hearing, CS-Home, and CS-School children.

while the CS-School children could perform better on the /ɔ̃/B,P→OM rule than on the /g/E,I→GU rule; (2) both graphonemes better spelled when included in high-frequency words than in low-frequency words; (3) a predominance of /ɔ̃/→ON and /*g*/→G errors in hearing and CS-Home groups, while CS-School children will also produce nonphonological mappings.

Method

Material. Each list contained three instances of the /ɔ̃/B,P→OM (or the /ã/B,P→AM) graphoneme and three instances of the /g/E,I→GU graphoneme (see Appendix). For each list, the score for the /ɔ̃/B,P→OM (or the /ã/B,P→AM) graphoneme was thus averaged over three items and the score for the /g/E,I→GU graphoneme was averaged over three different items.

Results and Discussion

Percentage of correct responses. For the /ɔ̃/→OM (or the /ã/→AM) graphoneme, a correct response was credited if the child spelled the phoneme /ɔ̃/ with OM (or the phoneme /ã/ with AM). For the word *température,* for example, responses like TAMPERATURE were considered as correct, while productions like TANPERATURE, TONPERATURE, and TRINPERATURE were considered as errors. For the /g/E,I→GU graphoneme, a correct response was credited if the child spelled the phoneme /g/ with GU. For the word *guéri,* for example, responses like GUERI and GUERRI were considered as correct, while responses like GERI, GRERI, and CRERI were scored as errors. The mean percentages of correct responses are presented in Fig. 4.

The data of the three groups were entered in a 3 (Hearing Status) × 2 (Type of Rules) × 2 (Frequency) ANOVA. The analysis revealed significant effects of Frequency, $F(1, 83) = 17.60$, $p < .001$, and of Type of Rules, $F(1, 83) = 6.33$, $p < .05$, but no effect of Hearing Status. The analysis also revealed a significant two-way interaction between Type of Rules and Hearing Status, $F(2, 83) = 3.21$, $p < .05$. Further analysis of this interaction revealed that the effect of Type of Rules was significant in the CS-School group, $F(1, 27) = 9.45$, $p < .005$, but not in the other two groups.

An analysis of spelling errors revealed that the most frequent error in spelling /ɔ̃/B,P→OM (or /ã/B,P→AM) mapping included in high-frequency words consisted of spelling N instead of M (hearing, 16.7% of the trials; CS-Home, 25%; CS-School, 11.9%). The number of such errors increased for low-frequency words in the hearing (24.2%) and CS-School groups (17.3%) and remained the same for the CS-Home group (25.0%). This indicates that the stronger /ɔ̃/→ON mapping is not entirely suppressed, in particular for low frequency words. Other errors (e.g., CROPETTE for *trompette*, BIDON for *guidon*, TAPERATURE for *température*) were fairly rare in the hearing and CS Home groups (<2.5%), but more frequent in the CS-School children, especially for low-frequency words (18.5% of the trials). For the /g/E,I→GU rule, most of the errors on high-frequency words consisted of spelling G instead of GU (hearing, 24.4% of the trials; CS-Home, 22.0%; CS-School, 33.9%). The number of such errors was striking for CS-School children, compared with 56.5% correct responses, thus indicating considerable indecision between the G and the GU spelling. The rate of G errors increased in the case of low-frequency words for hearing children (28.9%), remained the same for CS-Home children (22.6%) and diminished for CS-School children (29.8%). The number of other errors increased in low-frequency words for CS-Home (7.1%) and CS-School children (20.2%).

To sum up, the strong effect of frequency confirms that orthographic representations for these graphonemes are specified earlier in high-frequency than in low-frequency words (Alegria & Mousty, 1996). The considerable differences between the three groups in terms of the level of accuracy achieved for the /g/E,I→GU graphoneme indicate a specific difficulty in CS-School children in memorizing the orthographic form of words containing the /g/E,I→GU graphoneme.

Morphological Spelling

A limited amount of research has shown that children are sensitive to the morphological information conveyed in written words, with different conclusions about the developmental pattern. For example, in English, Treiman and Cassar (1996) showed that children in the early primary grades made fewer omissions on the last two consonants when these belonged to different morphemes, such as in *bars* and *tuned*, than when they belonged to the same morpheme, such as in *brand* and *Mars*. In French, Leybaert and Content (1995) studied whether children make use of inflectional morphology for spelling words like *grand*

(/grɑ̃/) and *bas* (/ba/). These words end with a silent consonant which is pronounced in morphologically related words like *grande* (/grɑ̃d/) and *basse* (/bas/). Hearing and deaf children in Grade 2 do not seem to use inflectional morphology in their spelling, while children at Grade 4 did, indicating that these kinds of morphological spellings in French are not mastered during the early years, but are acquired with later spelling development.

The extent to which children make use of morphological knowledge may vary with the quality of their phonological representations. Hearing and CS-Home children may use a morphological strategy for spelling, because they have a similar development of morphophonology in oral language. CS-School children may be less prone to use that kind of knowledge because of their marked difficulties in acquiring inflectional morphology (Hage, Alegria, & Périer, 1991; see also Leybaert et al., 1998).

In the present experiment, the use of morphological knowledge is tested measuring spelling accuracy for the graphemes S and T, which are unpronounced at the end of a large number of words. In the morphological condition these graphemes can be derived by thinking of morphological associated words, in which they are pronounced (e.g., S in *assis* /asi/, by reference to *assise* /asiz/), while in the nonmorphological condition they could not be derived (e.g., S in *jus* /ʒy/). A better performance on morphological graphemes than on nonmorphological graphemes would indicate the use of morphological knowledge for spelling. This allows the testing of the following predictions: (1) a larger gain displayed on morphological spellings for hearing and CS-Home children than for CS-School children and (2) a larger effect of frequency for nonmorphological spellings than for morphological spellings. While morphological knowledge may be used to control the spelling of high-frequency as well as of low-frequency words, correct spelling of nonmorphological knowledge depends only on orthographic knowledge.

Method

Material. In each list, the S and the T were tested three times as morphological graphemes (e.g., *assi***s** and *ba***s**) and three times as nonmorphological graphemes (e.g., *ju***s** and *concour***s**) (see Appendix). For each list, the score for morphological graphemes was thus averaged over six words, while the score for nonmorphological graphemes was averaged over six different words.

Results and Discussion

A correct response was credited when the child's production appropriately ended with S or T. For the word *assis,* for example, responses like ASSIS and ASSOIS were considered to be correct, while ASSI, ASSIC, and ASSE were scored as incorrect. The mean percentage of correct responses for morphological and nonmorphological graphemes as a function of word frequency is presented in Fig. 5 for the three groups of subjects.

The data of the three groups were entered in a 3 (Hearing Status) $\times$ 2

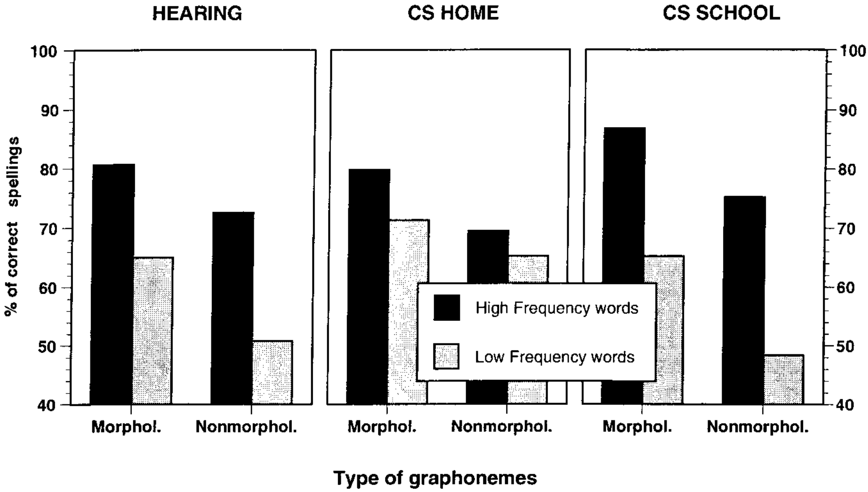

FIG. 5. Mean percentages of correct spellings for morphological and nonmorphological graphonemes as a function of word frequency for hearing, CS-Home, and CS-School children.

(Morphological Status) × 2 (Frequency) ANOVA with repeated measures on Morphological Status and Frequency. The analysis revealed significant effects of Morphological Status, $F(1, 83) = 41.96$, $p < .001$, and of Frequency, $F(1, 83) = 63.16$, $p < .001$. The analysis revealed no significant effect of Hearing Status, but did indicate a significant interaction between Frequency and Hearing Status, $F(2, 83) = 6.38$, $p < .01$. Further analysis of the Frequency by Hearing Status interaction revealed that the effect of Frequency was significant in hearing children, $F(1, 29) = 26.38$, $p < .001$, and CS-School children, $F(1, 27) = 47.19$, $p < .001$, but not in CS-Home children, $F(1, 27) = 3.2$. No other effect or interaction was significant.

The results thus show additive effects of morphology and frequency. Deaf and hearing children were more likely to spell final S and T when these were morphological graphemes than when they were not; they also spelled more accurately morphological and nonmorphological graphemes when these were included in high-frequency words.

GENERAL DISCUSSION

There are several important findings, the first of which pertains to the conditions that determine the use of phonology-to-orthography mappings. Most of the misspellings made by CS-Home children consist of phonologically accurate renderings of the target, suggesting that these children rely on accurate mappings between phonology and orthography. In spelling a word for which they do not have orthographic representation, they seem able to consider the word's phonological form first and then produce a combination of letters that represents it. Despite small differences between CS-Home and hearing children, the data clearly indicate that the development of phonology-to-orthography mappings does not in any way necessarily depend on the perception of auditory information. A visual system of signals that code all the phonological contrasts of a given language can promote this development. These data point to the linguistic, abstract, and amodal nature of phonology. Although phonology is often used to mean acoustic/auditory stimulus, or sounds, phonological units are not sounds. The phonological units are abstract linguistic units related to language gestures (Hanson, 1991). For children exposed to CS, phonological units could be related not only to lip movements but also to manual cues (Leybaert & Marchetti, 1997).

The second important finding is that the use of phonology-to-orthography mappings strongly depends on the accuracy of phonological representations. CS-School children have underspecified representations of phonology, which lead them to poor rhyming performance (Charlier & Leybaert, in press). In the present study, these children, although matched to hearing and CS-Home peers for general spelling level, made a lower proportion of phonologically accurate responses, particularly for low-frequency words. Their nonphonological errors may result from inaccuracy at the level of the phonological representations, from deficiency in segmentation of these representations, or from a difficulty in attributing graphemes to phonemes. Interestingly, CS-School children made a substantial number of nonphonological substitutions, which respect the "phonological skeleton" of the target in number of syllables and number of phonemes. These errors are indicative of an ability to segment the target into syllables and phonemes and to assign graphemes to these units (Bruck, Treiman, Caravolas, Genesee, & Cassar, 1998). Their spelling seems limited in the first place by the inaccuracy of their phonological representations. Some of their errors revealed a representation of phonology that is slightly deviant (e.g., TIGARETTE for *cigarette*), while others give little evidence of representation detailed at the segmental level (e.g., ESCORLE for *escalier*). The present findings thus indicate that acquisition of phonology-to-orthography mappings can be severely compromised when the input provided to the child is phonologically underspecified, as is the case for speechreading.

Before this discussion is pursued further, it is necessary to consider whether the differences between the CS-Home children and the CS-School children could result from some other, noncontrolled variable, rather than from the linguistic input children received early in life. The two groups of deaf children also differ from each other in several important dimensions, namely (a) hearing status of their parents, (b) amount of mainstreaming in ordinary schools for hearing children, and (c) reading level. Although these three factors certainly influence deaf children's cognitive development, they do not seem to be sufficient to explain the present results. First, children's exclusion from deaf parents did not change the pattern of effects, indicating that even CS-School children from hearing parents made a lesser use of phoneme-to-grapheme mappings than children from the other two groups. The second variable, school background, may be related to the results in two different ways. On one hand, teaching methods may be different in ordinary schools and in special schools for the deaf. These methods could influence the development of spelling procedures in deaf children, as they do in hearing children, at least at the beginning of spelling instruction (Bruck et al., 1998; Leybaert & Content, 1995). On the other hand, one may suppose that there exist differences in the cognitive profile of the children entering ordinary schools and special schools for the deaf, and that only the more able deaf children are schooled in the mainstream. The analysis with only the mainstreamed CS-School children is compatible with this idea, because the percentage of phonologically accurate responses was higher in this subgroup than in the whole group of CS-School children. Nonetheless, the percentage of phonologically accurate responses for low-frequency words was still lower in this subgroup than in the groups of hearing and CS-Home children. Finally, could the results be explained by differences in reading level? The reading level of CS-Home children requires a comment. It is the first time that children with profound and prelingual deafness have been found to achieve reading and spelling levels equivalent to those of their hearing peers at approximately the same chronological age (see also Wandel, 1990). This outcome shows that profound auditory impairment does not prevent children from learning to spell at the same rate as many hearing children do. However, the idea that the high rate of phonologically accurate responses of the CS-Home group is a consequence of their experience with print is unlikely, given other aspects of the data. The three groups were matched as closely as possible for spelling level, with the consequence that CS-School children were older and had a longer schooling experience. The success of this matching procedure is attested by the fact that the three groups performed similarly on aspects indicative of the development of orthographic representations: accuracy on nondominant graphonemes, accuracy on the /ɔ̃/ P,B→OM rule, and accuracy on nonmorphological spellings, for graphemes included in high-frequency words. To sum up, despite the limitations in the matching of the groups, which should be addressed by future research, the results thus suggest that use of phoneme-to-grapheme mappings is strongly determined by the children's experience with a phonologically well-specified input.

Finally, the results point to specific difficulties in acquiring orthographic representations which seem related to inaccuracy of phoneme representations. First, CS-School children exhibited a poor performance in spelling dominant graphonemes in less frequent words. This likely results from a lack of precision of phonological representations of low-frequency words. Second, CS-School children experienced more difficulties on spelling consonants when these were the coda of syllables than when they were at the beginning of syllables. This was also true, though to a lesser extent, for CS-Home children. These omissions are likely due to the fact that consonants in a coda position are not easy to perceive visually in speechreading, and even in CS. Third, CS-School children achieved a low level of accuracy for the /g/E,I→GU graphoneme, which seems related to the difficulty of perceiving the /g/ phoneme (Dodd, 1980). These results could not be explained by a differential exposure to written language, for the reasons already explained. Taken together, these data thus suggest that children's spelling has an important phonological component. The representations of the phonemes are associated with the graphemes and help to amalgamate the orthographic representations, as already suggested by different authors (Ehri, 1998; Frith, 1985; Perfetti, 1992, 1997).

The possibility that accurate spelling is dependent on the quality of phonological representations is also suggested by an alternative approach demonstrated by connectionist modeling. Such models, trained to associate phonological forms and spelling without any explicit rule at the phoneme-to-grapheme level, simulate performance observed in real learners (Brown & Loosemore, 1994). In the case of reading, the provision of phoneme-level representations computationally leads to selectively improved performance on pseudoword reading compared to word reading (Brown, 1997). Up to now, as far as I know, no equivalent simulation has been conducted on spelling. The results presented in this paper suggest that the quality of the phonological representations provided to such models could have an important impact on their learning efficiency for spelling. The rate of acquisition of word spelling would be slower in a model with deficient phonological representations than in a model with accurate phonological representations.

An unexpected result was the absence of differences between the three groups regarding the use of inflectional morphology for spelling, suggesting that quality of phonological representations does not play a role in that process. A likely explanation of the present results is that, given the quantity of such inflectional spellings in French orthography, children's better accuracy for morphological graphemes is the result of a statistical analysis of morphological mappings. By definition, words containing morphological spellings have morphologically related words. Exposure to these morphologically related words in written language increases the frequency of exposure to the stem. Seen from this perspective, the spelling of *petit* might benefit from the frequency of exposure to the written form *petite,* while the spelling of the nonmorphological T in *mot* can benefit from nothing other than the frequency of occurrence of this particular word. If this view is correct, children's spelling production system could be taught to extract morphological regularities through exposure to print, independently of the accuracy of phonological representations.

In summary, the present data show that spelling acquisition is possible with a visually acquired phonology, in the absence of useful hearing and limited expressive skills. They also point to specific spelling deficits exhibited by deaf children who mainly perceive spoken language through speechreading. The greater parts of these deficits are overcome when fully specified information about phonological contrasts is provided early and intensively to deaf children. It would be interesting to extend these findings in future research by investigating the impact of other systems aimed at complementing speechreading on the development of spelling in deaf children. The data reported here suggest that the analysis of how children spell words may be a good indicator of their phonological skills, as suggested by Treiman (1998).

APPENDIX: WORDS USED IN THE EXPERIMENT

Phoneme-to-grapheme dominance	High-frequency words: Dominant	High-frequency words: Nondominant	Low-frequency words: Dominant	Low-frequency words: Nondominant
/ɛ/	raisin (3.06)	bain (3.50)	poussin (2.28)	copain (3.43)
	sapin (3.18)	train (4.22)	marin (3.46)	parrain (2.65)
	lapin (3.30)	main (4.95)	moulin (3.25)	nain (2.68)
/s/	six (4.15)	citron (2.70)	secret (4.33)	cigarette (3.65)
	singe (3.21)	ciel (4.48)	sirop (2.57)	cerf (2.58)
	sel (3.31)	cinq (3.03)	sifflet (3.06)	cygne (2.91)
/k/	camion (3.33)	quoi (4.73)	corbeau (2.85)	quart (3.77)
	cadeau (3.33)	quand (5.15)	canif (2.36)	quai (3.65)
	carotte (3.14)	quatre (4.44)	collier (3.11)	quatorze (3.32)
Consonant	**Clusters CCV or (C)VCC**	**Controls (C)VCV**	**Clusters CCV or (C)VCC**	**Controls (C)VCV**
	fleurs (4.22)	*lapin*	grenouille (2.96)	radis (2.44)
	gris (3.98)	*raisin*	trompette (3.07)	revolver (1.41)
	train	rouge (4.28)	flèche (3.25)	ligne (4.31)
	armoire (3.42)	orange (3.07)	armée (4.50)	araignée (3.01)
	cartable (2.02)	*carotte*	guirlande (2.74)	quarante (3.75)
	escalier (3.98)	assis (4.15)	moustache (3.51)	casserole (2.86)
Context-sensitive rules	**/*N*/*p,b*→*M***	**/G/e,i→GU**	**/N/p,b→M**	**/G/e,i→GU**
	chambre (4.52)	guéri (3.26)	température (3.32)	guêpe (2.62)
	lampe (3.85)	guerre (4.63)	champignon (2.80)	guidon (2.13)
	jambe (4.05)	guitare (2.63)	*trompette*	*guirlande*
Morphological spellings	**Morphological**	**Nonmorphological**	**Morphological**	**Nonmorphological**
	trois (4.73)	jus (2.99)	épais (3.78)	*radis*
	gris	au-dessus (4.21)	repos (3.87)	repas (3.75)
	assis	en-dessous (3.52)	bas (4.32)	concours (3.48)
	mort (4.42)	mot (4.83)	début (4.09)	haricot (2.79)
	petit (5.17)	biscuit (2.69)	plat (3.72)	appétit (3.43)
	fort (4.67)	nuit (4.75)	départ (4.07)	maillot (2.59)

Note. The underlined part of the words corresponds to the graphemes tested in Part II. The words in italics are tested for different graphemes in Part II, but are written only once by the children. Mean log frequencies are in parentheses.

REFERENCES

Aaron, P. G., Keetay, V., Boyd, M., Palmatier, S., & Wacks, J. (1998). Spelling without phonology: A study of deaf and hearing children. *Reading and Writing: An Interdisciplinary Journal,* **10,** 1–22.

Alegria, J., Charlier, B., & Mattys, S. (1999). The role of lip-reading and Cued-Speech in the processing of phonological information in French-educated deaf children. *European Journal of Cognitive Psychology,* **11,** 451–472.

Alegria, J., & Mousty, P. (1994). On the development of lexical and non-lexical spelling procedures of French-speaking, normal and disabled children. In G. D. A. Brown & N. C. Ellis (Eds.), *Handbook of normal and disturbed spelling development: Theory, processes and interventions* (pp. 211–226). Chichester: Wiley.

Alegria, J., & Mousty, P. (1996). The development of spelling procedures in French-speaking, normal and reading-disabled children: Effects of frequency and lexicality. *Journal of Experimental Child Psychology,* **63,** 312–338.

Brown, G. D. A. (1997). Connectionism, phonology, reading and the regularity effect in developmental dyslexia. *Brain and Language,* **59,** 207–235.

Brown, G. D. A., & Loosemore, R. P. W. (1994). Computational approaches to normal and impaired spelling. In G. D. A. Brown & N. C. Ellis (Eds.), *Handbook of normal and disturbed spelling development: Theory, processes and interventions* (pp. 319–337). Chichester: Wiley.

Bruck, M., & Treiman, R. (1990). Phonological awareness and spelling in normal children and dyslexics: The case of initial consonant clusters. *Journal of Experimental Child Psychology,* **50,** 156–178.

Bruck, M., Treiman, R., Caravolas, M., Genesee, F., & Cassar, M. (1998). Spelling skills of children in whole language and phonics classrooms. *Applied Psycholinguistics,* **19,** 669–684.

Burden, V., & Campbell, R. (1994). The development of word-coding skills in the born deaf: An experimental study of deaf school-leavers. *British Journal of Developmental Psychology,* **12,** 331–349.

Campbell, R. (1994). Spelling in prelingual deafness. In G. D. A. Brown & N. C. Ellis (Eds.), *Handbook of normal and disturbed spelling development: Theory, processes and interventions* (pp. 249–259). Chichester: Wiley.

Campbell, R., Dodd, B., & Burnham, D. (Eds.). (1998). *Hearing by eye* (Vol. 2). Hove: Psychology Press.

Charlier, B., & Leybaert, J. (in press). The rhyming skills of deaf children educated with phonetically augmented speechreading. *Quarterly Journal of Experimental Psychology.*

Content, A., Radeau, M., & Mousty, P. (1990). BRULEX, une base de données lexicales informatisée pour le français écrit et parlé. *L'Année Psychologique,* **90,** 551–566.

Cornett, O. (1967). Cued Speech. *American Annals of the Deaf,* **112,** 3–13.

Dodd, B. (1976). The phonological system of deaf children. *Journal of Speech and Hearing Disorders,* **41,** 185–198.

Dodd, B. (1980). The spelling abilities of profoundly pre-linguistically deaf children. In U. Frith (Ed.), *Cognitive processes in spelling* (pp. 423–443). New York: Academic Press.

Dodd, B. (1987). Lip-reading, phonological coding and deafness. In B. Dodd & R. Campbell (Eds.), *Hearing by eye: The psychology of lip-reading* (pp. 163–175). Hillsdale, NJ: Erlbaum.

Dodd, B., McIntosh, B., & Woodhouse, L. (1998). Early lipreading ability and speech and language development of hearing-impaired pre-schoolers. In R. Campbell, B. Dodd, & D. Burnham (Eds.), *Hearing by eye* (Vol. 2, pp. 229–242). Hove: Psychology Press.

Duchnowski, P., Braida, L. D., Lum, D., Sexton, M., Krause, J., & Banthia, S. (1998). Automatic generation of cued speech for the deaf: Status and outlook. In D. Burnham, J. Robert-Ribes, & E. Vatikiotis-Bateson, (Eds.), *Proceedings of AVSP '98* (pp. 161–167).

Ehri, L. (1992). Reconceptualizing the development of sight word learning and its relationship to recoding. In P. Gough, L. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 107–143). Hillsdale, NJ: Erlbaum.

Ehri, L. (1998). Grapheme–phoneme knowledge is essential for learning to read words in English. In

J. L. Metsala & L. C. Ehri (Eds.), Word recognition in beginning literacy (pp. 3–40). Hillsdale, NJ: Erlbaum.

Erber, N. P. (1979). Speech perception by profoundly hearing-impaired children. *Journal of Speech and Hearing Research,* **44,** 225–270.

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia* (pp. 301–330). London: Erlbaum.

Gates, A. I., & Chase, E. H. (1926). Methods and theories of learning to spell tested by studies of deaf children. *Journal of Educational Psychology,* **17,** 289–300.

Gibson, E. J., Shurcliff, A., & Yonas, A. (1970). Utilization of spelling patterns by deaf and hearing children. In H. Levin & J. P. Williams (Eds.), *Basic studies on reading* (pp. 57–73). New York: Basic Books.

Hage, C., Alegria, J., & Périer, O. (1991). Cued Speech and language acquisition: The case of grammatical gender morpho-phonology. In D. S. Martin (Ed.), *Advances in cognition, education and deafness.* Washington, DC: Gallaudet Univ. Press.

Hanson, V. L. (1991). Phonological processing without sound. In S. A. Brady & D. P. Shankweiler (Eds.), *Phonological processes in literacy: A tribute to Isabelle Y. Liberman* (pp. 153–162). Hillsdale, NJ: Erlbaum.

Hanson, V. L., Shankweiler, D., & Fischer, F. W. (1983). Determinants of spelling ability in deaf and hearing adults: access to linguistic structure. *Cognition,* **14,** 323–344.

Hickson, L., Woodyatt, G., Cue, C., & Dodd, B. (in press). A longitudinal study of the linguistic abilities of children with severe and profound hearing impairment.

Hoeman, H. W., Andrews, C. E., Florian, V. A., Hoemann, S. A., & Jensema, C. J. (1976). The spelling proficiency of deaf children. *American Annals of the Deaf,* **121,** 489–493.

Leybaert, J., & Alegria, J. (1995). Spelling development in deaf and hearing children: Evidence for use of morpho-phonological regularities in French. *Reading and Writing,* **7,** 89–109.

Leybaert, J., Alegria, J., Hage, C., & Charlier, B. (1998). The effect of exposure to phonetically augmented lipspeech in the prelingual deaf. In R. Campbell, B. Dodd, & D. Burnham (Eds.), *Hearing by eye: Vol. 2. Advances in the psychology of speechreading and auditory–visual speech* (pp. 283–301). Hove: Psychology Press.

Leybaert, J., & Content, A. (1995). Reading and spelling acquisition in two different teaching methods: A test of the independence hypothesis. *Reading and Writing,* **7,** 65–88.

Leybaert, J., & Marchettti, D. (1997). Visual rhyming effects in deaf children. In C. Benoît & R. Campbell (Eds.), *Proceedings of the ESCAM workshop on audio-visual speech processing* (pp. 13–16).

Lobrot, M. (1973). *Lire.* Paris: E.S.F.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature,* **264,** 746–748.

Nicholls, G., & Ling, D. (1982). Cued Speech and the reception of spoken language. *Journal of Speech and Hearing Research,* **25,** 262–269.

Nunes, T., Bryant, P., & Bindman, M. (1997). Spelling and grammar—The necsed move. In C. Perfetti, L. Rieben, & M. Fayol (Eds.), *Learning to spell: Research, theory, and practice across languages* (pp. 151–171). Hillsdale, NJ: Erlbaum.

Peereman, R., & Content, A. (1999). LEXOP: A lexical database providing orthography–phonology statistics for French monosyllabic words. *Behavior Research Methods, Instruments & Computers,* **31,** 376–379.

Perfetti, C. A. (1992). The representation problem in reading acquisition. In P. B. Gough, L. C. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 145–174). Hillsdale, NJ: Erlbaum.

Perfetti, C. A. (1997). The psycholinguistics of spelling and reading. In C. Perfetti, L. Rieben, & M. Fayol (Eds.), *Learning to spell: Research, theory, and practice across languages* (pp. 21–39). Hillsdale, NJ: Erlbaum.

Périer, O., Charlier, B. L., Hage, C., & Alegria, J. (1988). Evaluation of the effects of prolonged Cued Speech practice upon the reception of spoken language. In I. G. Taylor (Ed.), *The education of the deaf: Current perspectives* (Vol.1, pp. 616–625). Beckenham, UK: Croom Helm.

Sprenger-Charolles, L., & Siegel, L. (1997). A longitudinal study of the effects of syllabic structure on the development of reading and spelling skills in French. *Applied Psycholinguistics,* **18,** 485–505.

Templin, M. C. (1948). A comparison of the spelling achievement of normal and defective hearing subjects. *Journal of Educational Psychology,* **39,** 337–346.

Treiman, R. (1993). *Beginning to spell: A study of first grade children.* New York: Oxford Univ. Press.

Treiman, R. (1998). Why spelling? The benefits of incorporating spelling into beginning reading instruction. In J. Metsala & L. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 289–313). Hillsdale, NJ: Erlbaum.

Treiman, R., & Cassar, M. (1996). Effects of morphology on children's spelling of final consonant clusters. *Journal of Experimental Child Psychology,* **63,** 141–170.

Véronis, J. (1986). Etude quantitative sur le système graphique et phono-graphique du français. *Cahiers de Psychologie Cognitive,* **6,** 501–531.

Walden, B. E., Prosek, R. A., Montgomery, A. A., Scherr, C. K., & Jones, C. J. (1977). Effect of training on the visual recognition of consonants. *Journal of Speech and Hearing Research,* **20,** 130–145.

Wandel, J. E. (1990). *Use of internal speech in reading by hearing impaired students in Oral, Total Communication and Cued Speech programs.* Unpublished master's thesis, Columbia University, New York.

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